Evolution of Globular Clusters: Effects of Tidal Shocks

Oleg Y. Gnedin & Jeremiah P. Ostriker

Princeton University Observatory
ognedin@astro.princeton.edu, jpo@astro.princeton.edu

Abstract. The semi-analytic theory of tidal shocks proves to be a powerful tool to study tidal interactions of star clusters and satellite galaxies with their massive hosts. New models of the globular cluster evolution employ a combination of analytic estimates, solutions of the Fokker-Planck equation and direct N-body simulations. The models predict large destruction rates for the Galactic globular clusters. Those on the highly eccentric orbits around the Galactic center are much more likely to be disrupted than the ones on nearly circular orbits. The destruction rates are largely increased near the bulge. Disruption of the low-mass clusters changes the Luminosity Function of the Globular Cluster System, shifting the peak of the Luminosity Function to the brighter end.

1. Introduction

Dynamical evolution of globular clusters is strongly affected by gravitational tidal shocks. When the clusters cross the disk of the Galaxy they experience disk shocking; when the clusters pass near the Galactic center, they experience bulge shocking. The effects of the tidal shocks depend on the density of the background stars and are especially pronounced in the inner regions of the Galaxy. Tidal shocks increase the energy of random motion of stars, reduce the binding energy of the cluster, accelerate core collapse, and lead to the faster overall evolution and destruction of globular clusters (for example, Spitzer 1987; Weinberg 1994; Murali & Weinberg 1997a,b,c; Gnedin & Ostriker 1997a).

2. Destruction of Globular Clusters

We calculate the rate of destruction of globular clusters as a result of various physical processes: two-body relaxation, evaporation of stars through the tidal boundary, disk shocking and bulge shocking (Gnedin & Ostriker 1997a). We use a Fokker-Planck code which includes tidal shocks semi-analytically. We introduce the adiabatic corrections that account for the conservation of adiabatic invariants of the fast moving stars (Gnedin & Ostriker 1997b). These corrections reduce the energy input due to the shocks in the inner parts of the cluster. The results (Figure 1) show that tidal shocks dominate cluster evolution near the Galactic center. Overall, as many as 50% to 90% of the present sample of globular clusters may be destroyed within the next Hubble time.

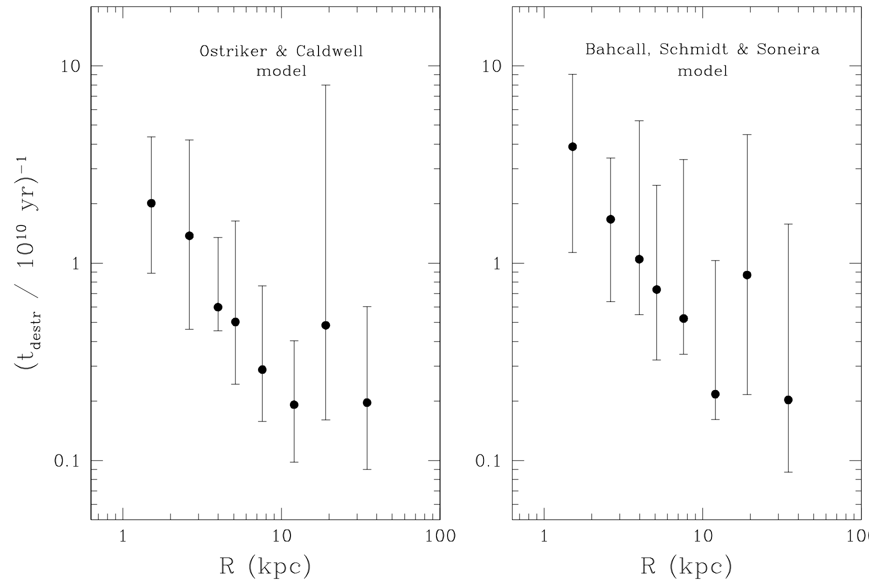

Figure 1. The destruction rates for the Galactic globular clusters, defined as the inverse time to destruction in units of 10^{10} yr, versus their present position in the Galaxy. The two panels show the results of the Fokker-Planck calculations for the two Galactic models and the isotropic velocity distribution of globulars.

3. Evolution of the Luminosity Function

Tidal shocks destroy most easily the low-mass, low-density clusters. Figure 2 shows the distribution of the inner and outer Galactic globular clusters. As expected, there are no low-density clusters in the inner part of the Galaxy where the tidal shocks operate most efficiently. Removal of those low-mass clusters makes the mean, or the peak, of the Luminosity Function (LF) to shift towards bighter magnitudes.

An apparent correlation of the masses and densities of outer clusters allows us to construct an intrinsic distribution of globulars, unaffected by the shocks. By applying the dynamical calculations, we can estimate the amount of brightening of the peak of the LF. Assuming that in all galaxies the initial distribution is the same, we can reconstruct the shock history in an external galaxy and infer the peak of the original distribution of globular clusters. Comparing that peak with the center of the intrinsic distribution in the Galaxy, we obtain a distance estimate to the galaxy. This method is fully independent and makes unnecessary the common assumption that the peak of the LF is a standard candle. Applied to the best known samples of M31 and M87 (Ostriker & Gnedin 1997), our method gives a distance estimate in very close agreement with that obtained with Cepheids and other methods.

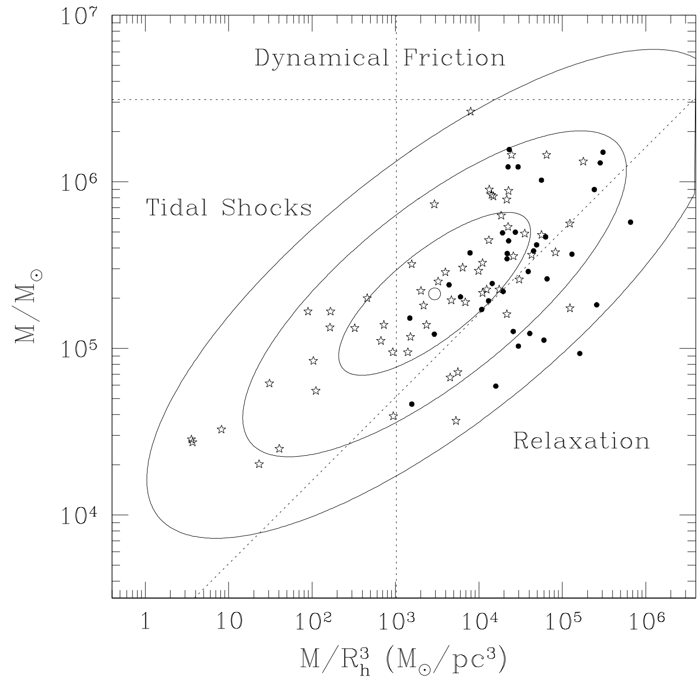

Figure 2. Distribution of the inner (green dots) and outer (red stars) Galactic globular clusters on the $\log M - \log \rho$ plane. The solid lines show the intrinsic distribution, where the ellipses are 1σ, 2σ, and 3σ levels, and the small circle is at the center of the distribution. The dotted lines mark the region allowed for the inner clusters by dynamical processes: above the horizontal line, dynamical friction is important, to the left of the vertical line tidal shocks are important, and below the diagonal line, relaxation will lead to core collapse and subsequent disintegration of the clusters.

4. Example: NGC 6712

Tidal heating can be simply parametrized to study semi-analytically the evolution of the individual clusters. We derive analytic equations for the first and second order energy changes, $\langle \Delta E \rangle$ and $\langle \Delta E^2 \rangle$, of stars in the cluster (Gnedin, Hernquist & Ostriker 1997). These equations are supplemented by the adiabatic corrections depending on the effective duration of the shock. Heating on the nearly circular orbits is strongly suppressed because the "shock" becomes very slow (Figure 3). The analytical estimates are tested against the Self-Consistent N-body simulations of the shocking event along a true trajectory of the cluster in the Galaxy. We find a remarkable agreement with the simulations.

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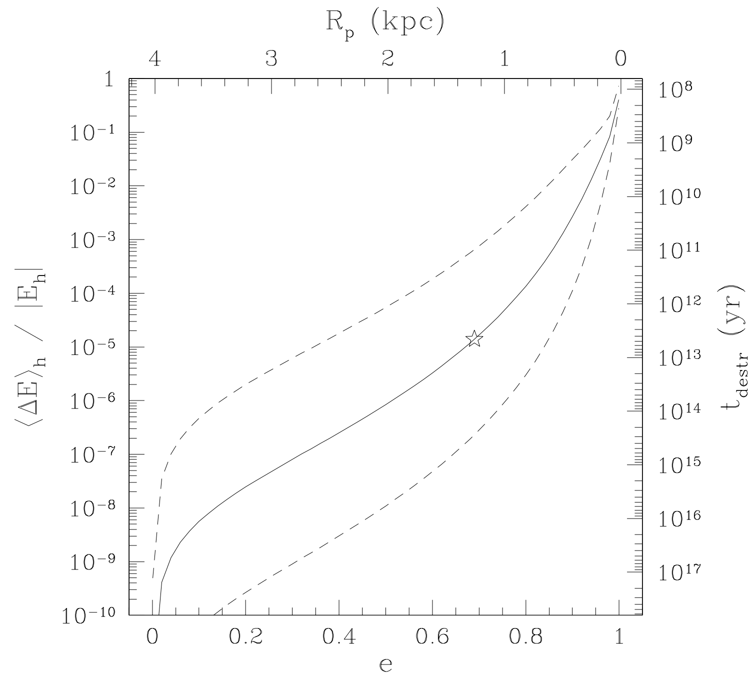

Figure 3. The energy change of stars at the half-mass radius of NGC 6712 relative to the initial half-mass energy as a function of eccentricity of the orbit. The orbital energy is fixed at the observed value for the cluster (red line) or at the one-half and twice that value (dashed green and blue lines, respectively).

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